## Design of Low-Rise Reinforced Concrete Buildings

### Errata to the first printing

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| 4-105  | 4.34   | Transverse reinforcing is not shown correctly in Section A-A.  
(See corrected Section A-A.) |
| 5-15   | 5.5    | Transverse reinforcing is not shown correctly in Section A-A.  
(See corrected Section A-A.) |
| 5-36   | 5.12   | Transverse reinforcing is not shown correctly in Section A-A.  
(See corrected Section A-A.) |
| 6-6    | 6.1    | Transverse reinforcing is not shown correctly in Section A-A.  
The arrows at Section A-A are not shown.  
(See corrected Section A-A.) |
| 6-21   | 6.7    | Transverse reinforcing is not shown correctly in Section A-A.  
(See corrected Section A-A.) |
| 6-22   | 6.8    | Transverse reinforcing is not shown correctly in Section A-A.  
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| 6-24   | 6.9    | Transverse reinforcing is not shown correctly in Section A-A.  
(See corrected Section A-A.) |
| 6-73   | 6.24   | Transverse reinforcing is not shown correctly in Section A-A.  
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| 6-74   | 6.25   | Transverse reinforcing is not shown correctly in Section A-A.  
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| 6-76   | 6.27   | Transverse reinforcing is not shown correctly in Section A-A.  
(See corrected Section A-A.) |
| 6-98   | 6.35   | Transverse reinforcing is not shown correctly in Section A-A.  
(See corrected Section A-A.) |
| 6-108  | 6.41   | Transverse reinforcing is not shown correctly.  
(See corrected section.) |
For SI: 1 inch = 25.4 mm; 1 foot = 304.8 mm.

Figure 4.34 Reinforcement Details for Column B1 Supporting the First Floor Level

Part 4: Determine reinforcement in footing B1

- Base Area of Footing

According to ACI 15.2.2, the base area of a footing is to be determined using service loads in whatever combination that governs the design. Basic load combination 6 in ASCE/SEI 2.4.1 is the critical load combination for footing B1 (see ASCE/SEI 12.4.2.3 and Table 4.30):

\[ P = (1 + 0.105S_{DS})P_D + 0.75P_L + 0.75P_{Lr} + 0.525P_{Q_E} = 201.5 \text{ kips} \]

From Table 4.23, the required base area of the footing is

\[ A_f = \frac{201,500}{4000} = 50.4 \text{ sq ft} \]

Use a 7 foot, 6 inch square footing \((A_f = 56.3 \text{ sq ft})\).
Figure 5.5 Transverse Reinforcement Requirements for Columns of Intermediate Moment Frames in Buildings Assigned to SDC C

The transverse reinforcement must extend above into the discontinued member and below into the supporting element in accordance with the provisions of ACI 21.6.4.6(b), which are illustrated in Figure 5.6.

For SI: 1 inch = 25.4 mm.
Diaphragm Design Forces

ASCE/SEI Equation (12.10-1) is used to determine the design seismic force, $F_{px}$, on the diaphragm:

$$F_{px} = \left( \frac{\sum_{i=x}^{n} F_i}{\sum_{i=x}^{n} w_i} \right) w_{px}$$

$$\leq 0.4 S_{DS} I w_{px} = 0.164 w_{px}$$

$$\geq 0.2 S_{DS} I w_{px} = 0.082 w_{px}$$

where $F_i$ = the seismic design force applied at level $i$

$w_i$ = the weight tributary to level $i$

$^{10}$ The effects from wind forces do not govern in this example.
proportions. The requirement that at least two bars be continuous at both the top and bottom of the section is for construction purposes.

![Diagram of flexural members of Special Moment Frames]

For SI: 1 inch = 25.4 mm.

*Figure 6.1 Summary of General Requirements for Flexural Members of Special Moment Frames*

### 6.2.3 Splice Requirements

Provisions for lap splices of flexural reinforcement are illustrated in Figure 6.3. Lap splices are permitted as long as they are properly confined with hoop or spiral reinforcement over the entire lap length and are located away from potential hinge areas (ACI 21.5.2.3).

In lieu of lap splices, mechanical and welded splices conforming to ACI 21.1.6 and 21.1.7, respectively, may be used (ACI 21.5.2.4).
6.3.1 General Requirements

ACI Section 21.6.1 is intended primarily for columns that are part of a special moment frame. Frame members other than columns that do not satisfy the general requirements of ACI 21.5.1 for flexural members of special moment frames are to be proportioned and detailed by the provisions of ACI 21.6.

The geometric constraints prescribed in ACI 21.6.1.1 and 21.6.1.2, which are illustrated in Figure 6.7, follow from previous practice.

![Diagram of special moment frame members subjected to bending and axial load.]

For SI: 1 inch = 25.4 mm.

Figure 6.7 Summary of General Requirements for Special Moment Frame Members Subjected to Bending and Axial Load

6.3.2 Minimum Flexural Strength of Columns

The intent of ACI 21.6.2 is to have columns in a special moment frame with sufficient strength so that they will not yield prior to the beams at a beam-column joint. Columns satisfying ACI Equation (21-1) are to be detailed in accordance with ACI 21.6.3 through 21.6.5.
If the provisions of ACI 21.6.2.2 are not satisfied at a joint, any positive contribution of a column at that joint to the lateral strength and stiffness of the structure is to be ignored, and the column must be designed and detailed in accordance with the requirements of ACI 21.13 for members that are not part of the seismic-force-resisting system.

6.3.3 Longitudinal Reinforcement Requirements

The longitudinal reinforcement requirements of ACI 21.6.3 are illustrated in Figure 6.8. The lower limit of the reinforcement ratio is to help in controlling time-dependent deformations and to ensure that the yield moment exceeds the cracking moment. The upper limit addresses concerns for steel congestion and high shear stresses that can be developed in columns with larger amounts of longitudinal reinforcement.

![Figure 6.8 Longitudinal Reinforcement Requirements for Special Moment Frame Members Subjected to Bending and Axial Load](image)

Requirements for splicing longitudinal reinforcement are also shown in Figure 6.8. Since spalling of the shell concrete is likely to occur at the column ends where stress reversal is expected to have a large stress range, lap splices must be located only within the center half of the member length. Special transverse reinforcement is required over the lap splice length due to the uncertainty in moment distributions along the height of the column and the need for confinement of lap splices subjected to stress reversals.
Figure 6.9 Transverse Reinforcement Requirements (Rectilinear Hoops) for Special Moment Frame Members Subjected to Bending and Axial Load
Figure 6.24 Requirements of ACI 21.13.3.2

Alternate 90-deg hooks

Transverse reinforcement determined in accordance with ACI 21.4.5

Section A-A

\[ M_u \leq \phi M_n \text{ and } V_u \leq \phi V_n \]

\[ A_g f'_c / 10 < P_u \leq 0.35 P_o \]

For SI: 1 inch = 24.5 mm; 1 degree = 0.01745 rad.

Figure 6.24 Requirements of ACI 21.13.3.2
Section A-A

\[ M_u \leq \phi M_n \text{ and } V_u \leq \phi V_n \]

\[ P_u > 0.35P_o \]

For SI: 1 inch = 24.5 mm; 1 degree = 0.01745 rad

*Provisions of ACI 21.6.5 and 21.6.4.7 must also be satisfied*
$6 \times \text{smallest longitudinal bar diameter}$

$L_{o} \geq \text{Clear span}/6$

$\ell_{o} \geq \text{Larger of } c_{1} \text{ or } c_{2}$

$Tension \text{ lap splice within center half of member length enclosed with transverse reinforcement in accordance with ACI 21.6.4.2 and 21.6.4.3}$

$s \leq \begin{cases} 6 \times \text{smallest longitudinal bar diameter} \\ 6 & \text{"} \end{cases}$

$0.01A_{g} \leq A_{st} \leq 0.06A_{g}$

$6d_{b} \geq 3"$

$6d_{b} \text{ extension}$

$A_{sh} \geq \begin{cases} 0.3(s_{b}c_{f}'/f_{yt})(A_{g}/A_{ch}) - 1 \\ 0.09(s_{b}c_{f}'/f_{yt}) \end{cases}$

$*\text{Provisions of ACI 21.6.5 and 21.6.4.7 must also be satisfied}$

$x_{i} \leq 14"$

$h_{x} = \text{largest value of } x_{i}$

$4" \leq s_{o} = 4 + \left(\frac{14 - h_{x}}{3}\right) \leq 6"$

$M_{u} > \phi M_{n}$ or $V_{u} > \phi V_{n}$, or induced moments not calculated

$p_{u} > A_{g}f_{c}'/10$

For SI: 1 inch = 24.5 mm; 1 degree = 0.01745 rad.

Figure 6.27 Requirements of ACI 21.13.4.3
Use a 3 foot, 4 inch splice length.

Reinforcement details for column B5 are given in Figure 6.35.

![Figure 6.35 Reinforcement Details for Column B5 Supporting the First-Floor Level](image)

For SI: 1 inch = 25.4 mm; 1 foot = 304.8 mm.

*Figure 6.35 Reinforcement Details for Column B5 Supporting the First-Floor Level*

**Part 3: Check the beam-column joint strengths at A5 and B5**

**Exterior Joint A5**

Since this joint is not confined on all four sides, the transverse reinforcement at the column ends is provided through the joint (ACI 21.7.3.2).

Figure 6.36 shows the exterior joint at level 1. The shear force at section x-x is determined by subtracting the column shear force from the tensile force in the top beam reinforcement assuming that the stress in the reinforcement is equal to $1.25 f_y$ (ACI 21.7.2.1).

Since the lengths of the column above and below the joint are equal, moments, $M_{ul}$, in the columns above and below the joint are equal to one-half of the negative probable flexural strength of the beam = $360.1/2 = 180.1$ ft-kips. Thus, the shear force, $V_h$, in the column at the top of the joint is:
\[
\frac{c_b + K_{tr}}{d_b} = \frac{1.5 + 0}{0.5} = 3.0 > 2.5, \text{ use } 2.5
\]

Therefore,

\[
\ell_d = \left( \frac{3 \times 60,000 - 1.0 \times 1.0 \times 0.8}{1.0 \sqrt{4000}} \right) \times 0.5 = 11.4 \text{ in.} < 12.0 \text{ in.}, \text{ use } 12.0 \text{ in.}
\]

In the plastic hinge zone, development length \(= 1.25 \times 1.0 = 1.25 \text{ ft}\)

Class B splice length \(= 1.3\ell_d = 1.6 \text{ ft}\)

Use a 1 foot, 8 inch splice length in the plastic hinge zone for the No. 4 vertical bars in the web. For simpler detailing, this splice length can be used over the entire height of the building.

The splice length of the No. 4 horizontal bars in the web is 1 foot, 4 inches. Since \(V_d > A_{el} f_{	ext{c}}\), the No. 4 bars must have a standard hook that engages the No. 8 edge reinforcement, or the No. 8 edge reinforcement must be enclosed in No. 4 U-stirrups spaced at 12 inches that are spliced to the No. 4 horizontal bars in the web (ACI 21.9.6.5(b)). The first of the two options is provided in this example.

Reinforcement details for the structural wall along line C are shown in Figure 6.41.

![Figure 6.41 Reinforcement Details for the Structural Wall on Line C](image)